U. S. DEPARTMENT OF AGRICULTURE

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PUMPING FROM WELLS for IRRIGATION

THE ESSENTIALS of a good pumping plant using well water are an ample supply of good water near enough to the surface for economical pumping, a well, properly constructed and developed, a pump capable of lifting the quantity of water needed, an engine or motor that will deliver sufficient power with minimum loss of efficiency and at minimum cost, and a carefully planned installation.

The sinking of a well which will produce an ample supply of water and the installation of an efficient and economical pumping plant require skill and knowledge not ordinarily possessed by the farmer. The purpose of this bulletin is to guide aright those interested in pumping from wells for irrigation by making available the most essential information pertaining to the sinking of wells and the selection, installation, and operation of pumping plants.

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PUMPING FROM WELLS FOR IRRIGATION[1]

By Paul A. Ewing,[2] *associate irrigation economist, Division of Irrigation, Bureau of Agricultural Engineering*

CONTENTS

INTRODUCTION

During the period from 1919 to 1929 the total irrigated area in the United States increased only 1.9 percent. During the same period, the area irrigated exclusively by pumping from wells[3] increased 62.4 percent; in the future, water pumped from underground sources is likely to play an even more important part in the irrigation of land.

The following considerations should have attention before money is spent for a well or pumping plant:

Is the quality of the water suitable for irrigation?

Is the ground-water supply available from wells sufficient to meet the requirements?

Will the pumping lift be permanently low enough to justify the expense involved?

Have similar undertakings succeeded in the locality?

Is the power to be used for pumping reliable and cheap?

Is the possibility of pumping for irrigation favorable from an engineering standpoint?

Has the legal status of pumping from wells been established in the area?

Besides considering these matters which pertain especially to irrigation by pumping from wells, the farmer has also to give thought to other general phases of irrigation such as the preparation of the land

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[1] A compilation of contributions by F. L. Bixby, C. E. Tait, Milo B. Williams, J. C. Marr, L. M. Winsor, P. E. Fuller, and F. J. Veihmeyer. Free use has been made of data and statements in publications of various State agricultural experiment stations.

[2] Revised by Carl Rohwer, with the assistance of members of the staff of the Division of Irrigation.

[3] Other large areas are irrigated in part by pumping from wells, but also receive water from other sources.

for irrigation, the suitability of the soil and topography for growing the proposed crops under irrigation, the climate, the accessibility of markets, and the rates charged locally on borrowed money. These are discussed in the following publications of the Department of Agriculture:

Farmers' Bulletins 864, Practical Information for Beginners in Irrigation; 1243, The Border Method of Irrigation; 1348, Corrugation Method of Irrigation; 1518, Orchard Irrigation; 1529, Spray Irrigation in the Eastern States; 1556, Irrigation of Small Grain; 1630, Irrigation Practices in Growing Alfalfa; 1635, Surface Irrigation in the Eastern States; Department Circular 197, The Credit Association as an Agency for Rural Short-time Credit.

THE LEGAL STATUS OF PUMPING

The legal status of pumping from wells for irrigation is not so well established as that relating to the appropriation of surface water. In some States the farmer is required to make application to the State for the right to appropriate ground water; in other States it is assumed that all landowners have common and correlative rights to use percolating ground water underlying their lands to the extent of their needs, or of a reasonable share of the supply. Where the ground-water level is being lowered from year to year, it is evident that when the latter doctrine is in force, each additional well will lower the ground water still farther, and all the earlier users from the same source of supply will have to pump their water from a greater depth. The farmer should consider these factors, and where the doctrine of appropriation applies to ground water he should file with the proper authorities an application to pump before starting construction of his plant.

THE WATER SUPPLY

QUALITY

Alkali and other mineral salts are sometimes present in solution in well water in sufficient quantities to be injurious to vegetation. If there is any question as to the quality of the water, an expert opinion should be obtained from the State agricultural college or some other qualified agency. The crops to be grown, the quantities of water to be applied, and the character of the soil have important bearings on the harmfulness of the alkali. These facts should be kept in mind when the suitability of the water for irrigation is being considered.

QUANTITY

The amount of water to be applied varies with the crop, the soil, the method of irrigation, and climatic conditions. The normal range is from less than 1 foot to about 4 feet in depth a year. A close estimate of the depth required can best be made by observing the efficient irrigation practice of the locality; but if there is no good example at hand the requirements under similar conditions in other sections may be taken as a guide.

Before considering the adequacy of a well as a source of water supply for a farm, it is necessary to know the maximum rate at which water will have to be applied. Suppose, for example, that

40 acres are to be irrigated and that the maximum irrigation requirement during the irrigation season will be 6 acre-inches of water per acre within a period of 10 days. The well then must be able to supply 20 acre-feet during a period of 10 days of continuous pumping, or at the rate of approximately 1 cubic foot of water per second.[4]

For economical distribution a flow of between 300 and 1,000 gallons per minute is desirable, but if a flow of less than 300 gallons is available a small storage reservoir, which may be filled during the night, will provide the necessary stream for the next day's irrigation if the pump is operated continuously. (See Farmers' Bulletin 1703, Reservoirs for Farm Use.) Wells supplying less than 100 gallons per minute sometimes can be successfully used for irrigating small tracts by means of either the furrow or sprinkler method of applying water. When a single well does not provide sufficient water, an additional supply can usually be obtained by putting down a battery of wells and connecting them to a single pump.

Unless an ample supply of ground water is known to exist, each promising water-bearing stratum should be tested carefully during the boring of the first well. If there is doubt as to the possibility of finding suitable water-bearing gravel, a test hole should be put down first. The ideal irrigation well is one having a small draw-down, even when being pumped at the maximum rate, and in which the ground-water level returns to within a foot or so of its original stage within a short time after the pump is stopped. There are, of course, fluctuations due to climatic conditions that are independent of those caused by pumping, but unless the yearly demand exceeds the supply the water should return to the normal level, or nearly so, before the beginning of the next irrigation season. Where the water table in a region has continued to lower for a period of years, caution should be exercised with reference to boring additional wells.

The possibility of obtaining a dependable water supply from a well is hard to determine except by sinking a test well. The Department of Agriculture places no credence whatever in "water witches." (See Farmers' Bulletin 1448, Farmstead Water Supply.) On high and semiarid plateaus it is not likely that water will be encountered at any depth that will make pumping feasible. On the other hand, in the valley of a large river having a sandy or gravelly bed, and on the adjacent benches or mesas, the chances of finding water in quantities sufficient to justify pumping are very favorable. This is often true either of a plain surrounded by high mountains and having little or no surface drainage, or of a desert valley traversed by a wide sandy river bed carrying spring floods and occasional freshets. Irrigated areas also are usually underlain by strata containing large supplies of ground water.

The presence of ground water at a suitable depth does not necessarily indicate that an adequate supply of water may be obtained. If the sand in the water-bearing strata is very fine, the yield of water will probably be small. The conditions are most favorable where the water-bearing strata are coarse sand or gravel of considerable thickness.

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[4] One cubic foot per second will give nearly 450 gallons per minute or approximately 2 acre-feet (sufficient water to cover 1 acre 2 feet deep) in 24 hours.

PUMPING LIFT

The lift (difference in height between the surface of the water in the well and that at the outlet) against which water for irrigation may be profitably pumped varies with the value of the crop to be grown. If the water is to provide only a supplemental supply as crop insurance, a greater lift is feasible than when the total supply has to be obtained by pumping. The 1930 Federal census of irrigation reported an average pumping lift from open and underground waters of 51 feet—an increase of 10 feet since 1920. Under exceptional conditions water has been pumped successfully against a lift of 500 or more feet. It is best to avoid the possibility of failure by undertaking to pump only where similar ventures have proved profitable or where a favorable report as to the feasibility of pumping has been given by some competent authority.

THE WELL

THE WELL SITE

If possible, a topographic survey should be made to permit choosing the best site for the well with reference to laying out a satisfactory system of ditches or pipes for irrigating the land. In general, the well should be located on the highest ground from which water can be conveyed economically in ditches to all tracts to be irrigated, unless distribution through pipes is planned, in which case a lower location may be better. In addition, the well should be located where the prospects for getting a satisfactory flow are good.

THE WELL CONTRACT

Usually the drilling of an irrigation well is provided for by a formal contract to protect both the farmer and the driller. The following considerations should have the attention of a farmer entering into such a contract:

A contract should specify the type of equipment which the driller is planning to use. The farmer should find out whether the equipment is in good condition and suitable for drilling the type of well proposed.

In some sections of the West, it is customary for the well driller to furnish casing, complete with starter section and strainer, if the latter is to be used. If screw casing is used, the contract should specify whether it is to be standard pipe or well casing, as well as the diameter and thickness. In the case of stovepipe casing, the diameter, gage, and quality of steel used, and whether the casing is to be single or double, should be stated. Complete details as to construction and materials used in the starter section and shoe should be given. When riveted casing is used, the kind of iron and whether it is black or galvanized should be indicated, as well as the gage and diameter. For large-diameter riveted casing, the dimensions and spacing of the reinforcing bands should be specified. The size and spacing of the perforations should be designated, and if the casing is to be perforated in place, the type of perforator should be named.

If concrete casing is used, type, size, thickness, mix, and size of openings should be specified. For wood casing, type, size, thickness, kind of wood, shape and dimensions of slot, and type of shoe should be given. Wood pipe should be used only where it will always be submerged or kept thoroughly saturated.

The dimensions of the well and the diameter and length of the different sizes of casing should be set out in the contract. Most well drillers insist on inserting a provision for minimum depth of well, and as a protection for the farmer the maximum depth should be specified so that the driller may not deliberately pass a desirable water-bearing stratum and drill to greater depth for the increased pay. The time of starting and completing the well should be specified, and provision should be made for developing and testing. The contract should call for delivery to the farmer of a complete and detailed log of the formations encountered in sinking the well and of location of casing and perforations in relation to the ground surface.

The prices to be paid for the various items involved in the construction of the well should be clearly set forth. The driller should be required to furnish bond or to advance all materials and labor and should not receive payment for partial completion of work. This protects the farmer in case it is necessary, through carelessness or mishap for which he is not to blame, to abandon the well and all or part of the casing.

Several large well-drilling companies work for a specified sum per day with no charge for time consumed in making repairs. Another arrangement specifies a lump sum for the drilling of a well of definite capacity. In such an arrangement, the well driller will probably set his price higher than is necessary so as to protect himself. Such arrangements often lead to serious differences of opinion.

When entering upon an arrangement of this type the farmer should specify that the draw-down of the water surface in the well shall not exceed a definite limit when the quantity agreed upon is being pumped and that the pumping shall continue until the draw-down becomes constant. The test should last long enough to clear the water. Inability to get clear water when pumping at full capacity usually indicates improper perforation or collapse or rupture of the casing, or an unsuitable strainer. Such a well should not be accepted.

In case it is anticipated that a turbine pump or other close-fitting apparatus is to be inserted in the well, the contract should specify that the bore of the well shall be plumb enough to permit the bowls to hang free; or it may be stipulated that a section of pipe, of such length and diameter as will insure such free suspension of the apparatus, shall pass freely down the bore.

THE WELL CASING

Well casing may be of metal, concrete, or wood, various materials being favored in different localities. Only the common types of steel casing are here described. The type of casing used depends on local practice and the nature of the material which it is expected will be encountered. Stovepipe casing is used in many water-bearing formations, but most successfully when coarse unconsolidated mate-

rials are encountered. This casing is usually perforated after the well is completed, by tools operated from within, which cut slits or gashes or punch holes with special shapes. In some cases when the locations of the water-bearing strata are known, the casing is perforated in advance. Screw casing also may be perforated and has the advantage over other casings that it will not come apart in caving material, and that it may be pulled out if the well is found to yield insufficiently. It is especially adapted to open-bottom wells in which the necessity may arise of drawing back to a certain formation after going beyond the desired depth. It may also be used in the sinking of wells, especially those 12 inches in diameter or smaller, where a strainer is to be inserted and the outer casing is to be withdrawn.

Riveted casing is especially adapted to shallow wells and to coarse sand and small gravel formations where hard driving or forcing is not necessary. It may be perforated in place but is usually perforated before being installed. When perforated before installation, the slots can be cut to exact size and spaced uniformly so that a large-capacity strainer can be obtained without dangerously weakening the casing.

DOUBLE CASING

Double well casing, sometimes called "stovepipe" casing, consists of inside and outside sections, usually 2 to 3 feet long, made so that the inside section can be forced into the outside section, thereby forming a double casing with a joint in the middle of each section. The sections are forced down, one at a time, as the well is deepened. The sections may be joined by riveting or welding. The surfaces in contact on the inside and outside sections are made smooth in riveted sections by countersinking the rivet holes and in welded sections by grinding off the beads. The heads of the rivets in the sections are placed so that the surfaces of the sections in contact will be smooth. The ends of the sections are faced in a lathe so that when they are forced together the ends butt evenly and squarely against each other and are held from slipping by each other. Sometimes as the sections are assembled they are profusely dented by a pick and so are kept from slipping apart in the well, in case the drilling tool should hang on the casing or on the shoe. Sometimes the sections are riveted or welded together.

Double well casing may be obtained in all diameters from 4 to 30 inches or larger. The 16-inch size is most often used in irrigation wells. The thickness of the casing varies from 8 to 16 gage, depending on the diameter and depth of the well. True stovepipe casing, known to the trade as "telescope casing", is made so that the end of one joint slips into the end of another joint about 1½ inches. It is suitable for only comparatively shallow wells and is short-lived.

A starter, usually consisting of eight 2-foot sections of casings of double or triple thickness riveted or welded together and then to a drive shoe, forms the first section upon which rests the "string of casing." If the material is fine and contains no boulders or hard material, the 2-ply, 16 to 10 gage starter, will be ample; otherwise the starter should be 3-ply. The drive shoe is slightly larger in outside diameter than the following casing, and as a result cuts a hole larger than the casing, which makes driving easier. The drive shoes used with stovepipe casing are usually larger and heavier than those

needed for other casing and have a shank which is riveted or welded to the casing; the latter slips over the shank and butts against the shoulder on the outside of the shoe.

Sometimes the casing is driven, for which operation a drivehead is used. This is composed of a heavy cast or forged steel cap, recessed so as to fit the top of the casing snugly. A pair of heavy clamps is bolted to the drill stem which is raised and allowed to fall as in the drilling stroke, the clamps striking the drive cap. Such casing has been driven as far as 200 feet in heavy boulder formation, though it is generally believed that it cannot be sunk except with hydraulic jacks or levers, sometimes called "pries", which exert a steady and uniform pressure. Generally the use of hydraulic jacks is preferred to driving.

Stovepipe casing is likely to fall apart in fine sands unless it is riveted or welded together before being sunk. To prevent this, a substantial footing for the casing must be found.

SCREW CASING

Screw casing may be standard wrought-iron pipe with ordinary outside couplings, but for heavy driving, extra-strong pipe, threaded to permit the ends to butt, and line pipe couplings should be used. "Inserted joint" casing has one end of each length threaded inside after being expanded slightly, thus reducing the resistance when the casing is being lowered. Joints so made will stand very little driving. Screw casing may be obtained in a number of weights, such as light well casing (about half as thick as standard pipe), standard, and extra-heavy pipe. When screw casing is used, whether with standard coupling or inserted joints, a steel drive shoe must be screwed and riveted or welded to the bottom of the first length of pipe. Such a shoe should be of a thickness that will permit it to be safely driven through hard strata or against boulders. It is usually from ¾ to 1 inch thick when used with large sizes of casing, and from ⅝ to ¾ inch thick for sizes below 10 inches.

RIVETED CASING

Riveted casing is composed of rolled steel sheets in sections from 24 to 36 inches in length, either plain or galvanized to make it rust-resistant. The thickness depends on conditions but usually varies between 16 and 8 gage. It is convenient to handle, but will stand only light driving and generally must be forced down by weights, hydraulic pressure, or pries. It is often used in diameters of over 20 inches for pit or dug wells, the weight of iron being proportioned to the diameter and depth of the well. This casing, especially in galvanized iron, may usually be obtained locally from sheet-metal shops. If of heavy iron, it must be obtained from boiler or pipe manufacturers at prices varying according to the gage.

Large-diameter casing is usually strengthened at the joints, the weakest places in the casing, by butting the ends together and using inside or outside collars riveted to each section. This precaution is necessary if the casing must be forced into a hard formation, and some kind of drive shoe at the bottom will be needed to prevent battering of the casing by boulders or other hard material.

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STRAINERS

Straıners have been used principally in fine-sand formations, but it has been found that where the water-bearing strata are of sand so fine as to call for special strainers, wells are likely to fail anyway, and in many sections this use has been discontinued owing to the expense involved and the uncertainty as to their effectiveness. Gravel envelops around the casing instead of strainers are now frequently used successfully and at much less expense if the well is not too deep. (See below.)

If conditions seem to call for a strainer, it should be of a type known to be successful in similar formations.[5] Some water may be pure enough for irrigation but still contain enough salts to corrode certain metals to the extent of closing the openings, or it may form deposits on the strainer, thereby rendering it useless. These facts should be kept in mind when considering the use of a strainer.

PERFORATIONS

Wells may fail to supply the amount of water they are capable of yielding because of insufficient perforation of the casing. Where possible, casing should be perforated before installation. While no definite rule can be given, it is recommended that the sections of casing to be perforated be provided with as many perforations as can be made without seriously weakening the casing. As much as 40 percent of the metal may be cut away, but the proportion must be varied according to the shape and size of the perforations, which are determined by the material to be screened. When perforated in place, slits from 4 to 6 inches apart should be made in each ring or circle, a space of 4 to 6 inches skipped, and a second ring or circle of slits then made, staggered with respect to the preceding set.

Under any conditions, the proper perforating of casing in place is difficult to effect, and it would be well for the farmer to request a visible test of the efficiency of the apparatus before an attempt is made to perforate the casing underground. Many wells that do not produce sufficient water after the first set of perforations is made are much improved by repeating the operation.

TYPES OF WELL

GRAVEL-ENVELOP WELL

In some sections the gravel-envelop or gravel-screen type of well is found to be very satisfactory. Perforated casing is put down in the usual manner, and as the casing goes down clean gravel is placed around the casing. The movement of the casing and the jarring by the well-drilling tools carries the gravel down with the casing. Care should be exercised to see that the gravel is provided free passage around the casing in the zone above the water level by making the well larger than the casing or by providing special passages for the gravel.

When properly made, the gravel-envelop well has many advantages over the type in which the casing is perforated in place, chief

[5] Water-Supply Paper 257, U.S. Geological Survey, Well-Drilling Methods, by Isaiah Bowman.

of which is the reduced resistance to flow near the well casing. Moreover, in fine-sand formations the gravel will replace the sand pumped out and this will prevent caving. The continuous screen of gravel insures free entry from every water-bearing stratum, whereas in perforating a casing after it is in place, the perforator may miss some of the water-bearing strata unless accurate records are kept during the drilling process and careful measurements are made during the perforating.

If temporary outside casing is used, it should be jointed strongly enough to permit its being pulled from the well. Stovepipe casing will not withstand this operation, but is sometimes used as the outer casing, being left in the well with the inner casing and the enclosed gravel screen. When this plan is followed, the outer casing, which is of large diameter (18 to 24 inches) is perforated in place opposite the water-bearing strata. The inner casing, which may be of either the stovepipe type or of the jointed pipe, is perforated before being inserted. Screened gravel is placed between the two casings after both are in place. This makes an expensive installation but one which has proved successful in many instances. It has the special advantage in some formations of affording double protection to the bowls of a deep-well turbine which might be lost or rendered ineffective by the destruction or collapse of a single casing as the result of caving.

OPEN-BOTTOM WELL

Many irrigation wells of the type known as "open-bottom wells" have been successful in stratified formations such as are found in many sections of the West. In this type the bottom of the casing is open, and all or part of the water enters through this open end. Often such a well is improved by perforating the casing to admit water from some higher stratum in addition to that coming from below.

The conditions most favoring an open-bottom well exist where the lowest water stratum tapped underlies a thick, hard layer in which the casing can be embedded firmly to form a foundation for the pipe and act as a seal to prevent water from carrying sand down from above, outside the casing. The presence of the hard layer or layers is essential to the success of the well. As an added precaution, the hole bored through the hard stratum should be at least 2 inches smaller in diameter than the casing.

The hard layer acts as a roof over the water-bearing stratum from which, if it is fine sand, the fine materials will be pumped out gradually until a large cavity is formed in the bottom of the well. Under such conditions it is necessary that the hard layer be thick enough to prevent serious caving. Should the roof give way under the test, it will be necessary to drive the casing through the water-bearing stratum and embed it in hard materials below. Perforations can then be made opposite the water, and the open-bottom well will be changed to a closed-bottom well. Screw casing is especially adapted to the construction of this type of well as it can not pull apart.

BATTERY OF WELLS

A battery of wells consists of several wells connected to a central pumping unit. This arrangement is feasible where natural con-

ditions limit the ground water available for pumping to 1 or 2 shallow strata of sand which give up water slowly. Because of the necessity for keeping within suction limits, the adaptability of the arrangement is limited further to formations in which the elevation of the ground-water table remains fairly constant.

Usually the suction lines or siphons which connect the several wells to the central pumping unit are laid in trenches or tunnels just above the maximum level of the water table. As these lines operate under a vacuum, great care must be exercised to prevent air leaks.

In most instances a horizontal or vertical centrifugal pump is used when a battery of wells is installed. The wells are either connected directly to the suction inlet of the pump by a suction header, or the water from the wells is brought by siphons to a central well of larger diameter over which the pump is placed. When siphons are used, a deep-well turbine pump may be placed in the central well. Such an arrangement is more satisfactory when the ground-water level is at a considerable distance beneath the surface, as this obviates the necessity of placing the pump in a deep pit.

Siphons have to be primed but if they are free from air leaks they will retain their priming for a considerable time. Horizontal or vertical centrifugal pumps usually have to be primed each time they are started. A large capacity vacuum pump should be used in priming siphons and centrifugal pumps with suction headers as a large volume of air has to be removed.

Ordinarily, though not necessarily, the battery of wells is located in a straight line along the boundary fence at the upper end of the land to be irrigated. Water enters the wells from all directions when the pump is operating, hence it is seldom necessary to place the line of wells at right angles to the line of flow of the ground water.

WELL DEVELOPMENT AND TESTING

Pumping equipment should not be purchased until the well is thoroughly developed and tested. If the pump is too large it must be throttled, or it will pump the well dry; if the pump is too small, the full capacity of the well will not be developed. Continuous throttling of the pump increases the power requirement, and the money thus spent for additional power is wasted. Often wells increase in capacity with the first pumping. This is especially true when the water-bearing material contains fine sand, silt, or clay which can be removed by pumping. Often, therefore, heavy pumping is desirable before a test is run.

It is impossible for pump manufacturers to supply efficient pumping machinery without accurate information regarding the conditions under which the plant must work, and they should be furnished with the following information when their estimates of costs are requested:

Well data:
- Inside diameter, length, and distance from ground surface to top of each size of casing.
- Total depth of well.
- Whether well is plumb, and if not how much out of plumb it is.
- Dimensions of pit.

Water conditions:

Capacity required in United States gallons per minute (g.p.m.).

Maximum amount obtained in test in gallons per minute.

Distance from ground surface to water level in well before pumping.

Distances from ground surface to water level in well when pumping different quantities of water, with distance and gallons per minute given in each case.

Estimated distance from ground surface to water level in well when pumping required amount.

Inside diameter, length, and difference in elevation between surface of ground at well and delivery point of discharge pipe.

Type of drive:

Whether pump is to be direct-connected to electric motor or belt-driven.

If motor driven, voltage, phase, and cycles.

If belt-driven, revolutions per minute (r.p.m.) of the engine, horsepower at pulley (hp.), and diameter of pulley.

Much of the information required can be obtained only by an adequate test of the efficiency of the well and such test should be made as soon as possible after the well is completed.

Before the test of a new well is begun the well should be developed by being pumped. For this purpose and for testing the well a centrifugal pump, deep-well turbine, or air-lift pump may be used. Centrifugal pumps can be used where the water is not to be drawn down more than about 25 feet below the center line of the pump; otherwise when the well is being pumped at the maximum capacity desired, deep-well turbines or air-lift pumps must be used. A tractor or other temporary power unit should be provided to operate the pump.

The average well should be developed slowly by controlling the discharge of the test pump. This is done either by varying the speed of operation or by opening the gate valve in the discharge pipe. A small quantity should be pumped at first. If sand appears in the water first pumped, the plant should be run with a uniform discharge until the water begins to clear. Then the gate valve can be opened or the speed of the pump increased until larger quantities of sand appear in the water, this operation being repeated until the capacity of the pump or well is reached.

When the development process is started, everything should be in readiness so that there will be little likelihood of having to stop the pump before the well has been pumped thoroughly. This is especially desirable when fine sand must be contended with, as stopping the pumping too soon may cause clogging of the well or pump. In other instances, when difficulty is experienced in starting the flow, it may be advisable to fluctuate the discharge by starting and stopping the pump in order to agitate the water in the well. This is known as "rawhiding."

Pumping water containing sand or silt continuously in any considerable amount speedily reduces the efficiency of the permanent installation by abrasion of the pump fittings. Such materials, moreover, are seriously detrimental if pumped into a pipe line or reservoir. To insure against such a possibility it is good practice to test the well as far beyond the proposed capacity of the permanent installation as is reasonably practicable.

In some sections, wells are developed by means of either the "mud scow" used in drilling the well or the surge block.[6] In either case

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[6] The Stovepipe or California Method of Well Drilling as Practiced in Arizona. Univ. of Ariz. Bul. No. 112.

the process is the same and consists of plunging the mud scow or surge block up and down, with fairly long strokes, opposite the perforations. The usual practice is to begin at the top, and gradually work down to the bottom of the well. The surging of the water draws the fine sand through the perforations into the well. As sand accumulates in the bottom of the well, it must be bailed out. The surging is continued until sand no longer comes into the well, and may take from one to several days. Very good results are obtained by this method.

As soon as the developing is completed, the well is ready to be tested; but before the test is started, pumping should be done for several hours at the maximum capacity of the well or of the testing apparatus. When there is no longer any apparent fluctuation in the discharge and the draw-down remains constant a careful meas-

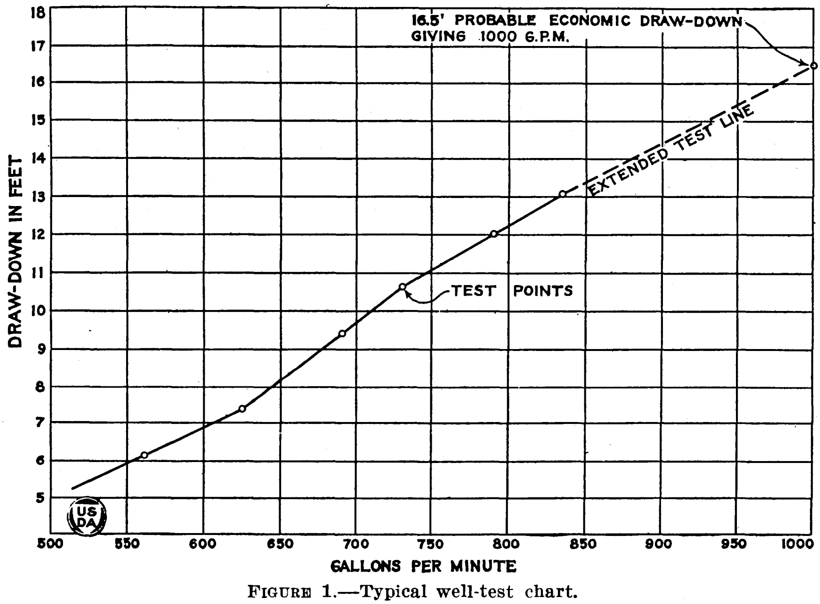

FIGURE 1.—Typical well-test chart.

urement of the flow should be made and the draw-down below the static level noted (p. 13). The discharge should then be reduced until the draw-down below the static level is only 4 feet. When this level has been maintained for about 15 minutes or the draw-down has become constant the discharge and draw-down should be measured accurately. The discharge should then be increased until the draw-down is 6 feet. The operation should be repeated with draw-down intervals of 2 feet until the capacity of the well or testing equipment has again been reached. In this way enough readings may be obtained to indicate the performance of the well at different lifts.

The results of the test should then be plotted graphically on a chart similar to that shown in figure 1. The vertical scale represents draw-down in feet, and the horizontal scale, discharge in gallons per minute. The rate of increase in flow per foot of draw-down is

indicated by the general slope of the line connecting the test points plotted on the chart, and the extension of the line beyond the last test point gives an indication of what may be expected if pumping is continued at higher rates. Such extension, however, should be used with caution as the discharge per foot of draw-down may drop off suddenly except where wells penetrate deep into the water-bearing material. From the test data, plotted as shown, a safe and economical lift can be assumed and the factors necessary for the design of machinery to fit the well can be determined.

The discharge may be measured with a suitable weir or flume as described in Farmers' Bulletin 1683, Measuring Water in Irrigation Channels. The weir can be installed in a properly designed box or in the bank of a small reservoir constructed for the purpose. Sometimes a length of discharge pipe equipped with an end orifice, properly calibrated, is used. An approved flow meter, such as is used by pump manufacturers, may also be employed.

DETERMINING THE DRAW-DOWN

The draw-down is the difference between the distance from the ground surface to the water surface in the well before pumping is started and the corresponding distance after the pump has been running long enough so that the surface of the water remains practically stationary. When a well is being tested with a centrifugal pump, the draw-down can usually be determined by direct measurement with a tape and float. If the pump is equipped with a vacuum gage it should be connected on the center line of the suction inlet. If the vacuum-gage readings are in feet the draw-down can be determined approximately by taking the difference between the vacuum-gage reading when the pump is primed and that taken when the pump is operating. If there is a foot valve on the suction pipe, the depth to the static water level should be measured with a tape because the vacuum-gage reading, when the pump is being primed, will not be correct if there is even a slight air leak. Furthermore, the results obtained by use of the vacuum gage during the operation of the pump are only approximate, as the gage also indicates the additional suction due to friction in the pipe and other losses. If a mercury gage is used, the difference in inches of mercury should be multiplied by 1.13 to get the difference in feet, and if the gage reads in pounds pressure the difference in pounds should be multiplied by 2.31 to get the difference in feet.

Deep-well turbines are frequently so installed that there is very little clearance between the bowls and the casing. When this occurs the tape-and-float and other direct methods of determining the draw-down cannot be used. Figure 2 illustrates a convenient way to determine the drawn-down under these conditions. A one fourth inch air tube of known length is placed in the well alongside the turbine. If possible, this tube should be long enough to reach at least 10 feet below the level of probable maximum drawn-down. The lower end of the airline pipe should be located at least 5 feet either above or below the suction-pipe inlet, since the relatively rapid flow at that point might affect the gage reading if the two intakes were too close together. To the upper end of the air line a pressure gage reading in feet and

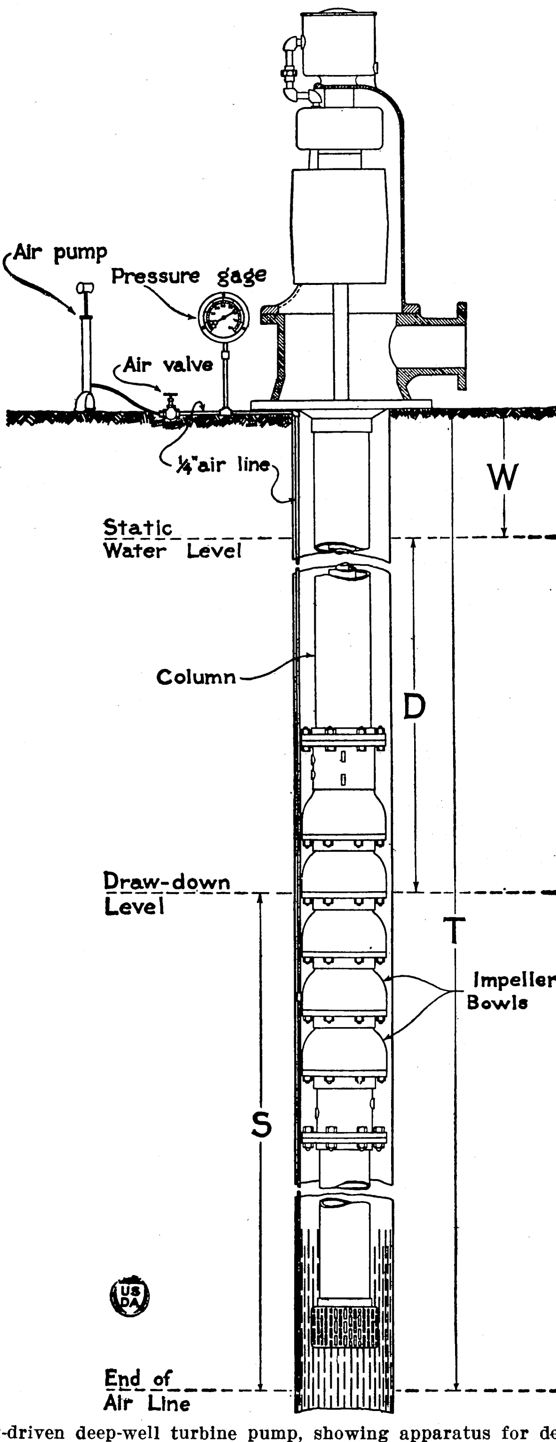

Figure 2.—Belt-driven deep-well turbine pump, showing apparatus for determining draw down.

a hand air pump with valve are attached in such a way that all the water can be forced out of the tube, and the air pressure in feet of water necessary to do this be read on the gage. When additional pumping into the tube does not increase the reading of this gage all the water is out of the tube. In the event that a gage reading in inches of mercury or pounds per square inch is used, the conversion to feet of water should be made, as previously explained, by multiplying by 1.13 for the mercury gage, and by 2.31 for the gage reading in pounds. The pressure in feet of water required to force all the water out of the tube shows the depth of submergence of the tube, and this value subtracted from the length of the tube, is the depth to water below the pump base at any stage of the test. The draw-down is the difference between readings of the gage taken when the pump is operating and when it has been standing idle long enough for the water in the well to reach its static level.

For example, assume the length of the air line, T, in figure 2 to be 100 feet. To determine the distance to the static water level, W, before the test is started all the water should be forced from the air line by use of the air pump, causing a gage reading, G, of, say, 79.7 feet. Then $100-79.7=20.3$ feet$=W$, the distance to water. If the gage reading had been in pounds per square inch the reading would have been 34½ pounds, which, when converted to feet by multiplying by 2.31, as before, also would equal 79.7 feet.

To determine the ultimate draw-down, or the draw-down at any stage of the test, the water is forced from the air line as in the preceding example, and the pressure gage is read. Assume that the reading, G, is 49.7 feet. Then 49.7 (S in the figure) subtracted from 79.7, ($S+D$ in the figure) gives 30.0 feet, which equals D or the draw-down.

Should this be the ultimate draw-down in the test, the total lift would be $D+W=30.0+20.3=50.3$ feet. This lift would be used in designing the plant.

THE PUMPING PLANT

THE PUMP CONTRACT

A formal contract should be drawn for the purchase of pumping equipment for the well. It is also desirable to have a contract to insure the installation of an efficient plant and to reduce the chances for disputes.

To eliminate controversies due to divided responsibility, the purchase and installation of the pump and motor or engine should be covered by a single contract. Then, if a question arises concerning any of the equipment, the farmer has to deal with the pump company only. The contract should specify exactly what is to be furnished by the pump company and what is to be furnished by the farmer. Care should be exercised to see that no accessories are forgotten, such as pressure gage and tube for measuring draw-down, starter, and wiring motor. The time limits on delivery and installation also should be specified.

The contract should show the guaranteed performance of the pump; that is, the horsepower required for pumping against the

normal lift and also for lifts 10 percent both above and below the normal. The data used should preferably be based on the actual results from the test of the well. The horsepower required under these conditions is measured at the meter for direct-connected units, and at the pump pulley for belt-driven installations. The method of measuring the lift depends upon the type of pump and should be clearly set forth in the contract. In centrifugal pumps it is the sum of the total suction lift, as measured by a vacuum gage at the center line of the suction inlet, and the lift, measured by a pressure gage at the center line of the discharge pipe at the pump, plus the difference in elevation between the points of connection of the two gages to the pipes. In deep-well turbines it is the vertical distance between the surface of the water in the well and the center of the discharge pipe at the pump, plus the total lift above this point, including allowance for friction in the discharge pipe line. The friction loss in the column of the deep-well turbine is not included.

Provision should be made in the contract for testing the pump. Either a factory or a field test is satisfactory, but it is advisable for the farmer to have an engineer present at the tests in order to eliminate disputes.

The time and method of payment for the equipment also should be specified in the contract.

TYPES OF PUMPS

The horizontal centrifugal, vertical centrifugal, and deep-well turbine centrifugal are the types of pump most commonly used as best adapted to raising water from wells for irrigation. For special conditions, plunger, air lift, and screw pumps are sometimes used.

HORIZONTAL CENTRIFUGAL

The horizontal centrifugal pump (fig. 3), when suited to the local conditions, is generally accepted as the cheapest in first cost and operation and the most reliable. Further advantages are its comparatively light weight, lack of valves and parts that wear out rapidly, simple operation and maintenance, easy accessibility, and relatively high efficiency. It is especially adapted to pumping 100 or more gallons per minute from either a single well or a battery of wells when the suction lift does not exceed 20 feet. A horizontal centrifugal pump cannot be operated when submerged and it cannot be used where the total suction lift exceeds the practical limit—20 to 25 feet at sea level.[7] If the vertical distance from ground surface to water level during pumping is not more than 40 feet, the pump may be installed in a pit and belt connected to an engine or motor at the ground level. From 15 to 20 feet is usually considered the maximum depth of pit for this type of pump when belt driven.

When the total lift (from water surface to outlet of discharge pipe) exceeds 150 to 250 feet, either the horizontal centrifugal type or the vertical centrifugal type (described later), if used, is usually "staged". Staging consists in installing additional runners or im-

[7] At 5,000 feet elevation the practical limit of suction is 17 feet, and at 10,000 feet it is 14 feet.

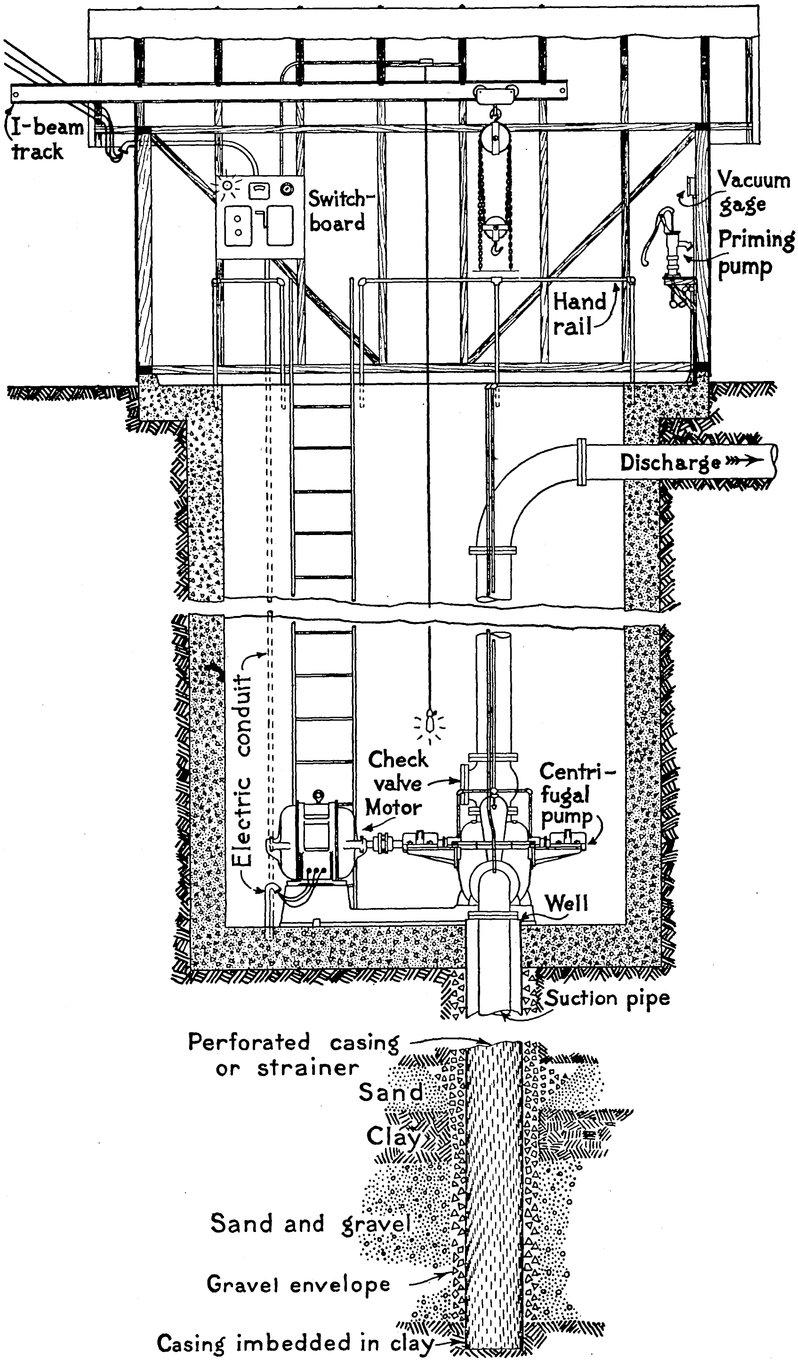

FIGURE 3.—Electrically driven horizontal centrifugal pump in pit.

pellers, each of which repeats the work of the preceding one, the combination being capable of forcing water through much higher lifts than a single stage pump can.

VERTICAL CENTRIFUGAL

In the vertical type of centrifugal pump the impeller is operated by a vertical shaft which may be of considerable length. It is adapted to wells where the depth to water does not exceed 50 feet when pumping is being done. The pump is usually set in the bottom of a pit below water level and is driven by an electric motor or engine, belt-connected to a pulley at the ground surface. The shaft must be supported by the pump discharge column or by a framework to prevent excessive vibration. A special type of vertical centrifugal pump, with the motor direct-connected to the pump, is sometimes used. This arrangement eliminates the necessity of having a long shaft, but the pump cannot be submerged.

The chief advantages of a vertical centrifugal over a horizontal centrifugal pump are that it will operate in a smaller pit and that no beltway need be provided when the pump is belt-connected with an engine or motor. Since this pump may be placed below the water surface it may be used where the water level fluctuates more than 20 feet. In fact, the pump is usually submerged to lessen suction lift and to eliminate the necessity for priming. The proper lubrication of pump and shaft bearings is likely to be a troublesome problem unless the shaft and bearings are enclosed in a tube. A vertical centrifugal pump costs more than a horizontal pump of the same capacity, and usually requires more power because of friction in the drive shaft, vibration of which is difficult to prevent as the bearings wear.

DEEP-WELL TURBINE CENTRIFUGAL

The deep-well turbine centrifugal pump, often called the "turbine type", is much used in irrigation. It is similar to the vertical centrifugal type in that the impellers or runners are incased in shells or bowls and the pump is driven by a vertical shaft placed inside the discharge column either in a tube when oil lubricated, or held by rubber bearings attached to spiders in the pump column when water lubricated. It usually consists of two or more bowls arranged in tandem, 10 to 30 or more feet constituting a stage (fig. 2). The name "turbine" comes from the diffusion vanes which guide the water from impeller to impeller.

This pump is compact and is adaptable to insertion in cased wells at considerable depths. It may be used in wells 10 inches and even less in diameter but is more efficient in the larger sizes, which occasionally are 24 inches in diameter or more. If the capacity of the well justifies installing a pump larger than will go into the well, the upper part of the casing is enlarged as far down as it is necessary to accommodate the bowls, and the suction is extended into the smaller casing or, in certain instances, attached directly to screw casing. It is especially adapted to lifts from 50 to 250 or more feet.

The deep-well turbine has an advantage over the horizontal centrifugal and vertical centrifugal types in that it is far less restricted as to lift, lubrication being effected from the ground surface except

in the case of water-lubricated rubber-bearing pumps. The depth at which the pump is set is limited neither by the expense of pit construction nor difficulty in attendance, but only by the cost of operation and by mechanical limitations of the pump itself. It does not require priming to start. High lifts and large volumes of water are handled without difficulty. The turbine pump is operated by means of an engine or motor at the ground surface, being belted to a pulley on the vertical shaft by means of either a flat belt or multiple V-belt, or direct-connected to a vertical motor incorporated in the pump head.

The turbine type is more expensive than the horizontal centrifugal or vertical centrifugal types. The latest models of this type are highly efficient and give little trouble when properly installed. They are best suited to places where the water level is more than 20 feet below the ground surface, or where the water level fluctuates widely. Their principal disadvantage, besides comparatively high first cost, lies in the expense and difficulty of making repairs, which usually involve the withdrawal of the entire pump from the well.

Manufacturers are likely to emphasize the ease with which the pump may be lowered to meet the requirements of a lowered water table, but this usually requires the installation of additional bowls or stages, necessitating the removal of the entire pump from the well. Consequently, the expense of reassembling the pump and fitting additional bowls should be given consideration.

PUMPS FOR USE UNDER SPECIAL CONDITIONS

The plunger pump, commonly used on the farm to raise water for domestic purposes, may be utilized in irrigating gardens, but for larger areas heavy-duty plunger pumps (fig. 4), with two-stroke cylinders and special power heads for operating the two pump rods, should be used. Double-action cylinder pumps are also made with a single rod. Such pumps have the advantage that the cylinders and valves may be withdrawn for inspection and repairs. The plunger pump is best adapted to irrigation when comparatively small quantities of water must be raised from great depths. When first installed it has the highest efficiency of any pump but, on the other hand, its first cost is high. The leathers, valves, and cylinders wear quickly where sandy water is pumped, and if high efficiency is to be maintained repairs must be made at considerable expense and loss of time.

The air-lift pump is particularly adapted to pumping from several wells using a central power house, wells that are too crooked for turbine pumps, and for pumping water carrying sand. The air-lift type consists essentially of a discharge pipe, an air line extending to the bottom of the discharge pipe, an air compressor, and a source of power. The absence of complicated working parts beneath the surface of the ground is an outstanding advantage of this pump. The submergence of the discharge pipe must be from 1 to 2 times the lift. The air-lift pump is relatively costly, and its efficiency is low. For these reasons it is generally not adapted to pumping for irrigation.

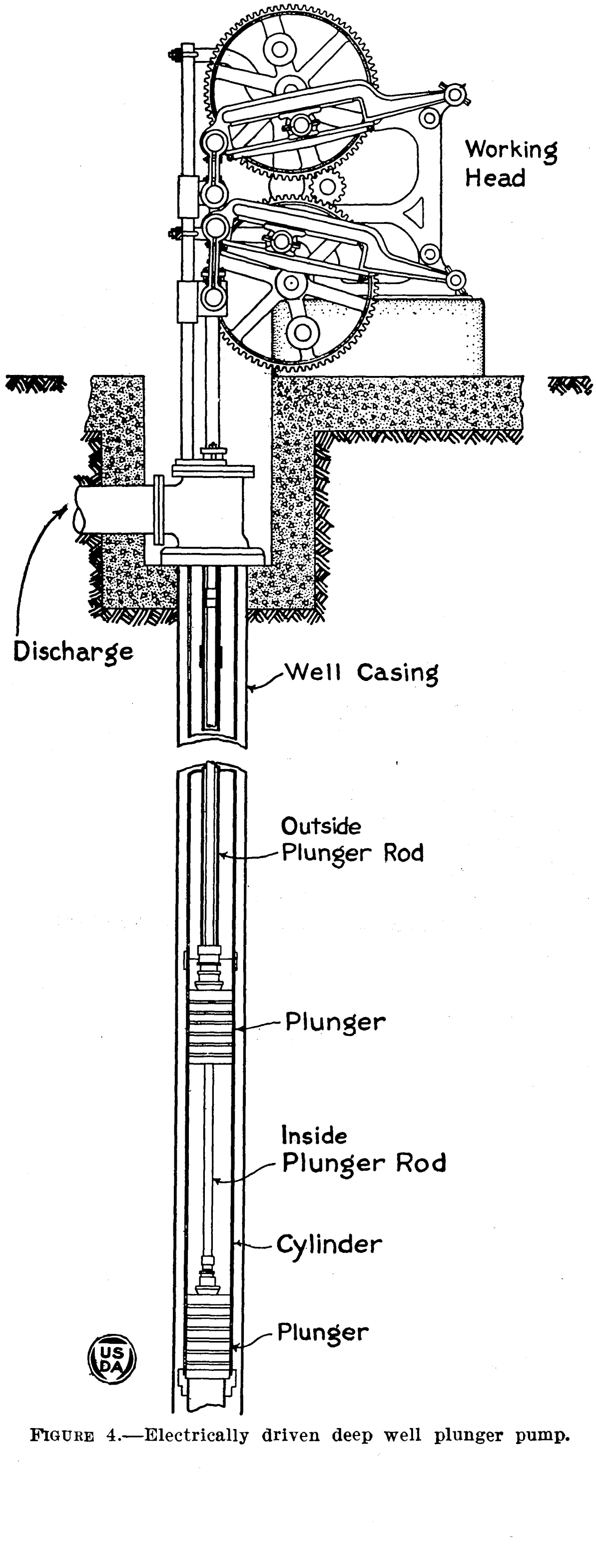

FIGURE 4.—Electrically driven deep well plunger pump.

A pump similar in form to the turbine, except that the water is lifted axially by screws instead of centrifugally by impellers, is obtainable for pumping large quantities of water from wells of small diameter. These pumps are known as " axiflow " and " direct-flow " turbines. Large in diameter, single-stage pumps of this type are very efficient in pumping large quantities against low heads. A combination of the screw and impeller type, known as the mixed-flow pump, combines the advantages of both types.

OTHER TYPES

The pumps already described are those chiefly used in irrigation from wells, and it is advisable to exercise caution in the purchase of any new and untried type, no matter what the principle of operation may be. Improvements in pumping equipment are being made constantly, but the advantages of any innovations should be demonstrated and well understood before they are adopted.

THE POWER UNIT

Ample power to operate a pumping plant without overloading the motor or engine must be available. This is particularly the case with respect to an engine. Some centrifugal pumps require additional power if the draw-down becomes less than was expected because they then pump more water. For this reason the plant should be designed to meet a load 10 percent greater than the estimated requirement. Some of the older types of centrifugal pumps were so designed that in using them there is danger of overloading when the lift is less than normal. Modern types, however, are equipped with what is known as a " nonoverloading impeller ", thereby insuring that, regardless of the lift or total head, the motor will not be called upon to carry an overload.

The power necessary to lift water is measured in horsepower.[8] Table 1 shows the approximate horsepower needed to lift different quantities of water to elevations of from 10 to 300 feet, assuming the efficiency of the plant to be 50 percent. Oil engines and motors are usually rated on brake horsepower. Engines and motors manufactured by reputable firms will deliver their rated horsepower. Motors may be overloaded as much as 10 percent in an emergency without injury, but it is never wise to deliberately overload oil engines, as difficulties in operation are almost certain to follow. Consideration should also be given to the effect of altitude in reducing the power from internal-combustion engines.

[8] One horsepower represents the energy required to lift 33,000 pounds 1 foot in 1 minute.

TABLE 1.—*Horsepower required to lift different quantities of water to elevations of 10 to 300 feet*

[Efficiency of pumping plant 50 percent of theoretical. Use for estimating only]

Gallons per minute	Cubic feet per second	Horsepower required for elevations of—							
		10 feet	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet
100	0.22	0.50	1.01	1.52	2.02	2.53	3.03	3.54	4.04
150	.33	.76	1.52	2.27	3.03	3.79	4.55	5.30	6.06
200	.45	1.01	2.02	3.03	4.04	5.05	6.06	7.07	8.08
250	.56	1.26	2.53	3.79	5.05	6.31	7.58	8.84	10.10
300	.67	1.52	3.03	4.55	6.06	7.58	9.09	10.61	12.12
350	.78	1.77	3.54	5.30	7.07	8.84	10.61	12.37	14.14
400	.89	2.02	4.04	6.06	8.08	10.10	12.12	14.14	16.16
450	1.00	2.27	4.55	6.82	9.09	11.36	13.64	15.91	18.18
500	1.11	2.53	5.05	7.58	10.10	12.63	15.15	17.68	20.20
600	1.34	3.03	6.06	9.09	12.12	15.15	18.18	21.21	24.24
700	1.56	3.54	7.07	10.61	14.14	17.68	21.21	24.75	28.28
800	1.78	4.04	8.08	12.12	16.16	20.20	24.24	28.28	32.32
900	2.01	4.55	9.09	13.64	18.18	22.73	27.27	31.82	36.36
1,000	2.23	5.05	10.10	15.15	20.20	25.25	30.30	35.35	40.40
1,250	2.78	6.31	12.63	18.94	25.25	31.57	37.88	44.19	50.50
1,500	3.34	7.58	15.15	22.73	30.30	37.88	45.45	53.03	60.61

Gallons per minute	Cubic feet per second	Horsepower required for elevations of—							
		90 feet	100 feet	125 feet	150 feet	175 feet	200 feet	250 feet	300 feet
100	0.22	4.55	5.05	6.31	7.58	8.84	10.10	12.63	15.15
150	.33	6.82	7.58	9.47	11.36	13.26	15.15	18.94	22.73
200	.45	9.09	10.10	12.63	15.15	17.68	20.20	25.25	30.30
250	.56	11.36	12.63	15.78	18.94	22.10	25.25	31.57	37.88
300	.67	13.64	15.15	18.94	22.73	26.52	30.30	37.88	45.45
350	.78	15.91	17.68	22.10	26.52	30.93	35.35	44.19	53.03
400	.89	18.18	20.20	25.25	30.30	35.35	40.40	50.51	60.61
450	1.00	20.45	22.73	28.41	34.09	39.77	45.45	56.82	68.18
500	1.11	22.73	25.25	31.57	37.88	44.19	50.51	63.13	75.76
600	1.34	27.27	30.30	37.88	45.45	53.03	60.61	75.76	90.91
700	1.56	31.82	35.35	44.19	53.03	61.87	70.71	88.38	106.06
800	1.78	36.36	40.40	50.51	60.61	70.71	80.81	101.01	121.21
900	2.01	40.91	45.45	56.82	68.18	79.55	90.91	113.64	136.36
1,000	2.23	45.45	50.51	63.13	75.76	88.38	101.01	126.26	151.52
1,250	2.78	56.82	63.13	78.91	94.70	110.48	126.26	157.83	189.39
1,500	3.34	68.18	75.76	94.70	113.64	132.58	151.52	189.39	227.27

The horsepower may be derived from the following formula:

$$\text{Horsepower} = \frac{\text{g. p. m.} \times h}{3{,}960 \times E}$$

where g.p.m. = gallons pumped per minute,

h = total lift in feet against which pump must work. This includes the total vertical distance between the water surfaces plus frictional and other losses.

E = the efficiency of the pump expressed as a fraction. It is the ratio of the water horsepower to the horsepower applied to the pump shaft.

The horsepower given by the formula is the power applied at the pump pulley. The efficiency specified by the pump manufacturer is the E used in the formula. It must be kept in mind that friction caused by the movement of the water in the suction and discharge pipes, obstruction to the flow caused by changes in velocity, bends, valves, etc., offer further resistance which must be overcome by the pump. These losses, converted to feet of additional height through which the water must be lifted, are taken into account in the h in the

above formula. In table 1 the horsepower of the engine or motor specified is taken as twice the horsepower theoretically required, as this will be approximately the horsepower required to operate the plant. In reality, however, as indicated in table 3, p. 25, the value of *E* increases with the size of the pump.

THE ELECTRIC MOTOR

Where electric current is obtainable at reasonable cost, it is the most satisfactory source of power for irrigation pumping. Electric motors combine reasonably low cost, safety, high efficiency, reliability, and ease of operation.

Each motor of the type used in pumping has a particular speed which is practically constant under all conditions, but the range of speeds available in the various sizes of electric motors is such that they are readily adapted to the operation of pumps. Electric motors may be direct-connected to the pump shaft, thereby eliminating friction and slippage losses due to transmission through belts or gears. Direct-connected electric plants are compact and require less housing than plants of other types, and avoid the trouble of purchasing, hauling, and storing fuel.

Rates charged for electric power are based usually on kilowatt-hour [9] consumption and horsepower of connected load, which is ordinarily determined by the name-plate rating of the motor. The rates charged for power vary in different sections. The schedules shown in table 2 give a general idea of the range in cost of such service.

TABLE 2.—*Rates charged for electricity*

Size of installation (horsepower)	Annual demand charge per horsepower	Energy charge in addition to the demand charge; rate per kilowatt-hour for consumption per horsepower per year of—		
		First 1,000 kilowatt-hours	Next 1,000 killowatt-hours	All over 2,000 kilowatt-hours
	Dollars	*Cents*	*Cents*	*Cents*
2 to 4	[1] 6.50	1.5	1.2	0.8
5 to 14	5.50	1.32	1.1	.8
15 to 49	5.00	1.17	1.0	.8
50 to 99	4.50	1.12	.9	.8
100 and over	4.00	1.07	.9	.8

[1] The annual minimum charge is the demand charge.

The foregoing schedule (table 2), which applies in California, gives very low rates. The following schedule gives rates which are more nearly equal to the charges elsewhere:

	Cents per kilowatt-hour [10]
First 100 kilowatt-hours per season per horsepower	5
Next 200 kilowatt-hours per season per horsepower	3
Next 500 kilowatt-hours per season per horsepower	2
All additional kilowatt-hours per season per horsepower	1.5

[9] One kilowatt-hour equals 1,000 watt-hours, equals 1.34 horsepower hours.
[10] The minimum charge is the charge for the first 100 kilowatt-hours per season per horsepower.

Some companies charge for power at flat monthly rates, and some, to encourage continuous use of power, quote their rates upon the farmer's total connected load instead of on the separate motors.

Frequently, where electric power is to be utilized, several miles of power line must be provided in order to tap the line of some power company, and secondary lines must be constructed to each pumping plant. The cost of these power lines, especially when they are long, is an important item in the cost of pumping plants. Ordinarily it is met at first by the consumer, but some companies divide it with their customers or refund it in service.

THE INTERNAL-COMBUSTION ENGINE

Internal-combustion engines are efficient and with proper care will continue to be so through comparatively long periods. This is especially true of the diesel and semidiesel types, which are built in sizes suitable for all but the smaller plants. Ordinarily an engine will last from 8 to 12 years. Some farmers pump water only a few days per week, or only a few hours per day; others operate their plants continuously day and night, and the length of the irrigation season varies widely in different localities; hence the life of an engine used to operate a pumping plant cannot be estimated closely in years. Its life in hours depends on four factors: the quality of material and workmanship put into its manufacture, the load it operates under, the attention given to its operation, and the fuel used. Engines sold by reputable manufacturers are usually well built and constructed of good material.

A heavily loaded engine will not last as long as one lightly loaded, a load of 75 or 80 percent of the rating of the engine usually being the safe maximum. A substantial foundation is necessary to reduce vibration, and in order to avoid belt trouble the location and alignment of the pump and engine pulleys should be in accordance with the recommendations regarding these matters furnished by the pump or engine company from which the purchase is made. An engine should have a sight-feed pressure lubricator and an ample cooling system. Good lubrication oil should be used. Proper housing of an engine is important, particularly in a country where freezing weather and sand storms occur. Dust, grime, rain, and neglect cause rapid depreciation. Every engine should be cleaned at regular intervals, and bolts, springs, valves, and other parts should be examined and necessary repairs made.

Suitability of fuel is an important factor. One obstacle to the continued use of the internal-combustion engine is the uncertainty as to whether it will always be possible to obtain a supply of fuel oil at a price making its use practical, and it is well to select an engine which will run on more than one grade of oil. An engine using the heavier grades of oil should be chosen since it will work with the lighter oils when the cheaper grades are not available. Cheap oils which are too heavy or contain too much asphalt should not be used.

Clean combustion is very important in prolonging the life of an engine. A smoky exhaust indicates a foul, dirty cylinder, injurious deposits, and rapid wear. Engine performance depends principally on the condition of the cylinders, piston rings, and carburetor or fuel injector; other parts can be maintained in good order by occasional adjustments or minor repairs.

SELECTING, INSTALLING, AND OPERATING A PUMP

Under ordinary circumstances the horizontal centrifugal type is best adapted to conditions where the water level is never more than 40 or 50 feet beneath the ground surface when pumping is being done, a pit being utilized for depths greater than 25 feet. Where the water level drops lower than 40 or 50 feet beneath the surface, either the vertical centrifugal or the turbine pump may be used. Where the water is at a greater depth, the deep-well turbine should be used for flows greater than 200 gallons per minute. The plunger pump is to be considered when the head is great and the quantity of water to be pumped is not more than 200 gallons per minute, but for this condition also small deep-well turbines are now available. Turbine pumps may be obtained for wells as small as 4 inches in diameter. The air lift is restricted neither as to lift nor quantity of water to be pumped, but its low efficiency limits its usefulness to the special conditions already mentioned.

Centrifugal pumps of any of the three types described should be selected to fit given conditions of lift and capacity. This is true also of screw pumps. Too often the only condition stipulated by the farmer in ordering a pump is that it discharge a specified quantity of water. It should be remembered that it is possible to obtain widely varying quantities of water from a centrifugal or turbine pump by varying the speed of its operation, but there is only one set of conditions of discharge and speed under which centrifugal and turbine pumps will operate at maximum efficiency for a given head. A pump bought in ignorance of this fact, with cheapness as the main consideration, will prove more costly in the long run than the initially more expensive but efficient pump. For this reason, second-hand pumps should not be purchased unless it is certain that they are suited to the existing conditions.

The demand charge will be higher than is necessary if a motor with more power than is required is used; consequently both motor and pump should be chosen with reference to the actual power requirements and should be of standard sizes.

The approximate capacities and efficiencies of different sizes of centrifugal pumps (not including the turbine type) are given in table 3. In ordinary practice a good pumping plant, properly installed, should easily show the efficiency given.

TABLE 3.—*Typical capacities of centrifugal pumps and the horsepower required for their operation under average conditions* [1]

Centrifugal pump no.	Discharge per minute	Theoretical horsepower per foot of lift	Pump efficiency	Actual horsepower per foot of lift [2]	Centrifugal pump no.	Discharge per minute	Theoretical horsepower per foot of lift	Pump efficiency	Actual horsepower per foot of lift [2]
	U.S. gallons		*Percent*			*U.S. gallons*		*Percent*	
2	200	0.050	40–60	0.10	6	1,000	0.252	70–80	0.36
3	300	.076	65–75	.12	8	2,000	.505	70–80	.72
4	500	.126	65–75	.19	10	3,000	.757	70–80	1.10
5	700	.177	65–75	.27					

[1] The efficiencies listed are for pumps properly designed and installed for heads of 40 to 60 feet. Plant efficiencies can be estimated by subtracting 10 percent for direct-connected electric motors and 15 to 20 percent for belt-connected motors.

[2] Efficiencies taken as the lower value in the preceding column.

The amount of power lost in forcing a given quantity of water through a pipe varies with the length, size, age, and kind of pipe, the number and sharpness of the bends, the valves, and other obstructions to the flow. All these factors increase the total head against which the pump must operate, and in designing a plant, provision must be made for the additional power required. When a bend must be made in the discharge or suction pipe, a long-radius elbow should be used. The suction pipe must be airtight and should extend at least 10 feet below the level to which the water will be drawn. The discharge pipe should be carried no higher than necessary, as each foot in height increases the cost of pumping.

The requirements for air lift and plunger pumps are more flexible than those for centrifugal pumps. The discharge from these pumps may be varied without having a material effect on the efficiency, but such plants also should be carefully designed as the investment in the equipment is relatively large.

COST OF PUMPING

It is beyond the scope of this bulletin to give costs of pumping-plant installations in such detail that they will be generally applicable throughout the irrigation region. In order that prospective purchasers may have clearly in mind the items that usually enter into the cost of pumping plants, estimates of the costs of plants of the two types in most common use are given. Conditions peculiar to different communities will qualify these estimates, and the cost reported should be considered as suggestive only. Before a plant is purchased, quotations on the equipment it is proposed to install should be secured from reliable dealers. The cost of transmission lines for electrical power is omitted because it depends on local conditions. The farmer should ascertain what expense would be involved in bringing electrical current to his plant from the nearest power line, and what refunds would be made in case the initial expense were charged to him.

CASE NO. 1

ELECTRICALLY DRIVEN CENTRIFUGAL PUMP IN PIT (SEE FIG. 3)

(Estimate based on Colorado conditions)

Conditions:

- Crop to be irrigated, alfalfa.
- Depth of water required on land, 2 feet in four irrigations, in a 30-day rotation in 6-inch applications.
- Amount of water furnished by well, 2 second-feet=900 gallons per minute, which will provide a 6-inch depth over 4 acres each 12 hours or a 6-inch depth over 120 acres in thirty 12-hour days or fifteen 24-hour days.
- Lift of water=40 feet (includes 10 feet above pump).
- Theoretical or water horsepower, 9.1.
- Plant efficiency, 65 percent.
- Motor required, 15 horsepower (actually 14 horsepower).

Cost of plant:

Well 50 feet deep, drilling, including gravel-envelop developing and testing at $6 per foot	$300.00	
Casing, 24-inch, 14-gage, galvanized and perforated, 40 feet at $2.50 per foot	100.00	
Shoe	10.00	
Pit, 8 by 8 by 10 feet inside, concrete 6-inch walls and bottom	150.00	
Total		$560.00

Cost of plant—Continued.		
Pump no. 6, single-stage, bronze impeller, horizontal centrifugal, direct-conducted to 15-horsepower motor, installed, with necessary electrical and hydraulic accessories	$740.00	
Pump house, with 1-ton chain block, concrete floor, pit, railing, etc	200.00	
Total		$940.00
Total cost of plant		1,500.00
Cost per acre ($1,500÷120)		12.50
Cost of operation per season:		
Interest on $1,500 at 7 percent	$105.00	
Taxes and insurance at 2 percent	30.00	
Depreciation of machinery (value $740) at 10 percent	74.00	
Depreciation of house and well (value $760) at 5 percent	38.00	
Power consumed 10.4 kilowatts for 1,440 hours at 2½ cents per kilowatt-hour	374.40	
Repairs, lubricating oil and attendance per season	30.00	
Total		651.40
Cost of pumping per season ($651.40÷120)		5.43
Cost of pumping per acre-foot of water ($5.43÷2)		2.72

CENTRIFUGAL PUMP IN PIT, DRIVEN BY OIL ENGINE

It is estimated that a 15-horsepower oil engine of the semideisel type could be installed in the plant described in case 1, the necessary changes being made in pit and house design at an approximate cost of $2,300.

Cost per acre for oil engine plant $2,300÷120 .... $19.17

COST OF OPERATING WITH OIL ENGINE

Interest on $2,300 at 7 percent	$161.00	
Taxes and insurance at 2 percent	46.00	
Depreciation of machinery (value $1,400) at 10 percent	140.00	
Depreciation of house, well, and pit, with necessary changes for engine (value $900) at 5 percent	45.00	
Fuel oil consumed 1.3 gallons 32-gravity oil per hour for 1,440 hours at 5½ cents per gallon	102.96	
Repairs, lubricating oil, and attendance per season	200.00	
Total cost of operating per season		694.96
Cost of pumping per acre per season ($694.96÷120)		5.79
Cost of pumping per acre-foot of water ($5.79÷2)		2.90

CASE NO. 2

ELECTRICALLY DRIVEN DEEP-WELL TURBINE PUMP (SEE FIG. 2)

(Estimate based on California conditions)

Conditions:

Crop to be irrigated, fruit.

Depth of water required on land, 1.5 feet in three irrigations in a 60-day rotation of 6-inch applications.

Amount of water furnished by well, 1 second-foot=450 gallons per minute, which will irrigate 2 acres 6 inches deep each 12 hours, or 120 acres in sixty 12-hour days, or thirty 24-hour days.

Lift, 100 feet.

Theoretical or water horsepower, 11.4.

Plant efficiency, 60 percent.

Motor required, 20 horsepower (actually 19 horsepower).

Cost of plant:		
Well 200 feet deep, drilling at $2 per foot, perforating included	$400.00	
Developing and testing	150.00	
Casing, 16-inch double stovepipe, 12 gage, 180 feet at $2.75	495.00	
Casing starter, 20 feet, 3-ply and ring	100.00	
Total		$1,145.00
Pump, deep-well turbine installed on concrete base with direct-connected vertical 20-horsepower motor	$1,100.00	
Electrical and hydraulic accessories, installed	150.00	
Pump house, 8 by 8 by 7 feet	100.00	
Total		1,350.00
Total cost of plant		2,495.00
Cost of plant per acre ($2,495÷120)		20.79
Cost of operation per season:		
Interest on $2,495 at 7 percent	$174.65	
Taxes and insurance on $2,495 at 2 percent	49.90	
Depreciation on machinery (value $1,250) at 10 percent	125.00	
Depreciation of well and building (value $1,245) at 5 percent	62.25	
Power consumed 14.1 kilowatts for 2,160 hours at 2 cents per kilowatt-hour	609.12	
Repairs, lubricating oil, and attendance per season	100.00	
Total cost of operation per season		1,120.92
Cost of pumping per acre per season ($1,120.92÷120)		9.34
Cost of pumping per acre-foot of water ($9.34÷1.5)		6.23

DEEP-WELL TURBINE PUMP, DRIVEN BY OIL ENGINE

It is estimated that the plant described in case 2 could be installed with a 20-horsepower semidiesel engine, enlarged pump house and foundation for approximately $3,600.

Cost per acre of oil-engine plant ($3,600÷120)	30.00

COST OF OPERATING PER SEASON WITH OIL ENGINE

Interest on $3,600 at 7 percent	$252.00	
Taxes and insurance on $3,600 at 2 percent	72.00	
Depreciation of machinery (value $2,300) at 10 percent	230.00	
Depreciation of well, pump house, etc., (value $1,300) at 5 percent	65.00	
Fuel consumed, 2 gallons, 32-gravity oil per hour for 2,160 hours at 5 cents per gallon	216.00	
Repairs, lubricating oil, and attendance per season	350.00	
Total cost of operating per season		1,185.00
Cost of pumping per acre per season ($1,185÷120)		9.88
Cost of pumping per acre-foot of water ($9.88÷1.5)		6.59

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